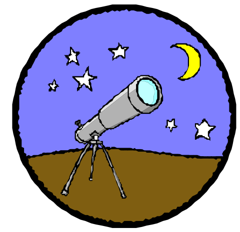
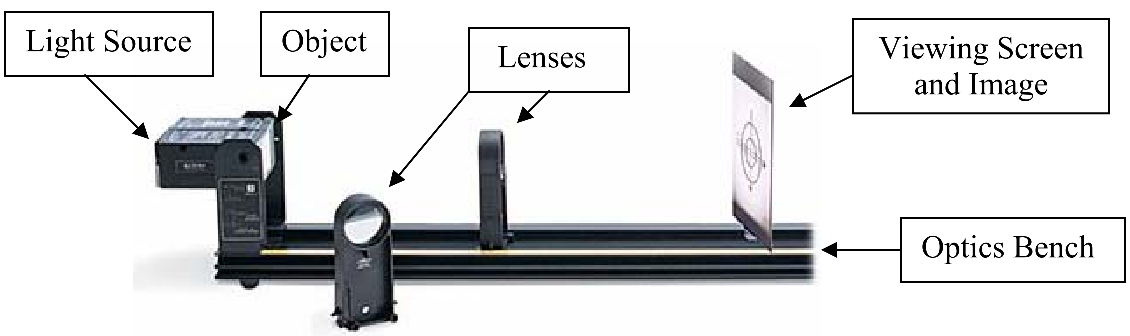
# *Thin Lenses*



**Introduction** Thin lenses have many applications. For example, they are used in microscopes, binoculars, eyeglasses, contact lenses, magnifying glasses, cameras and refracting telescopes. Consequently, we encounter them frequently in everyday life. As you know, the physics of a thin lens is relatively simple in that about all a thin lens does is form an *image*. However, as usual, there are some subtleties involved since images can be *real* or *virtual*. Further, the image formed by a thin lenses can be a real or virtual object for another lens. Consequently, it is worthwhile spending some time firming up our understanding of thin lenses. The laboratory is an excellent place to do that since a real image can be displayed on a screen (flat, white surface). As a consequence, we can measure where the real image is relative to a lens and compare its position with that predicted by our equations. Further, we can carry out experiments that involve virtual images. Though virtual images can't be displayed on a screen, they still produce important effects. What we will do is study combinations of lenses where the role of the virtual image can be inferred.

**Equipment** The equipment consists of a light source, lenses, viewing screen and an optics bench (slotted aluminum track for fixing the light source, lenses and screen in position). The "object" is the drawing (concentric circles, perpendicular arrows and scale) on front of the light source. An image of the object is visible on the screen in the following picture.




**Theory** As you know, if an object is a distance $d_o$ (object distance) from a thin lens of focal length $f$ and forms an image at a distance $d_i$ (image distance) from the thin lens, the relationship between $d_o$, $d_i$ and $f$ is

Text eq. [34-2] $$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \qquad (1)$$

The sign convention for each of these quantities is given on page 841 of the textbook. For example, a *converging lens* has a positive focal length and is sometimes referred to as a *positive lens*, etc. Next, if the object has a height $h_o$, and the image has a height $h_i$, the lateral magnification is given by

Text eq. [34-3] $$m=\frac{h_i}{h_o}=-\frac{d_i}{d_o} \qquad (2)$$

The *magnitude* of $m$ has the usual meaning e.g. if $m$ = 2, then the image is twice as large as the object. The subtlety is that the *sign* of $m$ is also meaningful e.g. if $m$ is negative, then the image is inverted (flipped over and reversed from right to left) relative to the object.

**Lens Characteristics** Our first goal is to characterize the lenses.

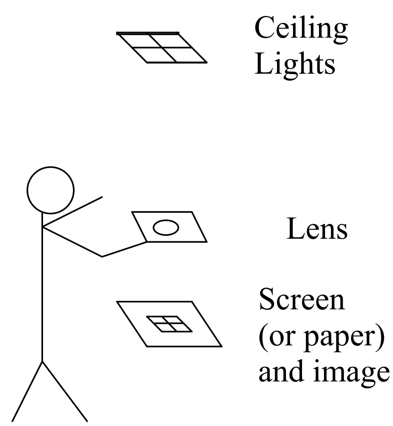
1. Feel the shape of each of the lenses.

R1: Is the blue lens thicker or thinner in the middle? Should the blue lens be diverging or converging?

R2: Is the yellow lens thicker or thinner in the middle? Should the yellow lens be diverging or converging?

R3: Is the red lens thicker or thinner in the middle? Should the red lens be diverging or converging?

2. Let us attempt to confirm these predictions. In fact, *only converging lenses can form real images of real objects* and we will use this fact to decide whether our predictions are correct. Using the technique shown at the right, attempt to form an image of the ceiling lights (real objects) with each of the lenses.




R4: Does the blue lens form a real image? Is the blue lens diverging or converging?

R5: Does the yellow lens form a real image? Is the yellow lens diverging or converging?

R6: Does the red lens form a real image? Is the red lens diverging or converging?

**Note:** We have made the assumption that the object distance is greater than the focal length. As can be seen from eq. (1), converging lenses only form real images (positive $d_i$) of real objects if the object distance (positive $d_o$) is greater than the focal length (positive $f$). If $d_o$ is less than $f$, then a converging lens will form a virtual image (negative $d_i$) that can't be displayed on a screen. Consequently, since the focal lengths of the lenses are fairly small, you will only have arrived at the correct conclusion if you kept the lens the expected (far) distance from the ceiling lights. However, if, for some strange reason, you stood on the table or whatever and placed any of the converging lenses near the ceiling lights, you would not have observed a real image and hence concluded incorrectly that the lens is diverging.

We will now determine the focal length of each of the lenses.

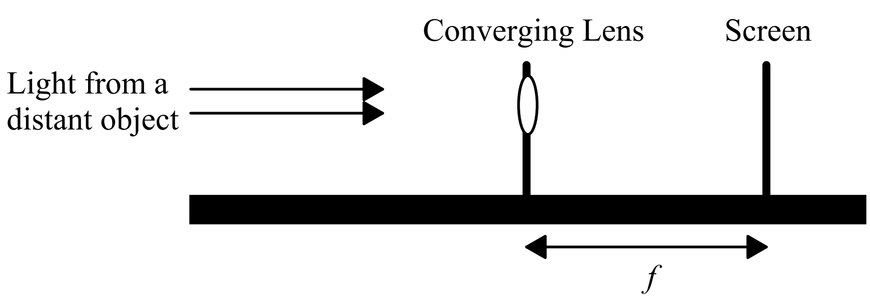
***Converging Lens*** For the *converging* lenses, there is a direct way to determine the focal length. Notice that when $d_o = \infty$ (the object is very far away from the lens) eq. (1) becomes

$$\frac{1}{\infty} + \frac{1}{d_i} = \frac{1}{f} \tag{3}$$

In this case, $d_i = f$. This implies that *when the object is very far away from the lens the image distance equals the focal length*. Let us carry out that experiment for each of the converging lenses.

1. Carefully remove the light source from the optics bench. If it is bright and sunny outside, take the converging lenses, the optics bench and the screen to the hallway that runs the length of Michelson and Chauvenet. **(Do not go outside since it will be too bright to easily observe images on the screen. The best way to carry out this experiment is to make your observations through the windows.)** If it is too dark outside, take the equipment just outside the lab (corridor A of Michelson Hall). There will be a light bulb (and a lighted exit sign) at one end of corridor A. Go to the other end.

2. Arrange the equipment as shown in the next sketch and obtain an image (on the screen) of something very far away. (Be sure that the screen is perpendicular to the optics bench.) If you are looking through the windows, try for the light poles. If you are in corridor A, obtain an image of the light bulb or the lighted exit sign.




3. Determine the distance from the lens to the screen. If you are looking through the windows, you may find it helpful to shade the screen (reduce the stray, background light) somehow to make the image visible. (In fact, the lights in the hallway should be turned off.) Record the distance from the lens to the screen as the focal length in the space provided. Be sure to add a plus sign (to indicate that the lens is converging) and estimate and record the uncertainty.

4. Repeat steps 2 and 3 for the other converging lens. (Spaces are provided for all lenses. If the lens is diverging, leave the space blank.)

R7: $f_{\text{blue}}$ = ________ ± ________ cm R8: $f_{\text{yellow}}$ = ________ ± ________ cm

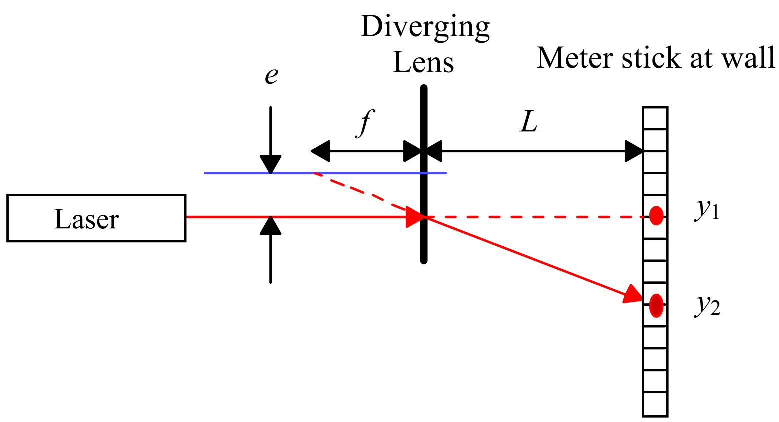
R9: $f_{\text{red}}$ = ________ ± ________ cm

***Diverging Lens*** Since virtual images cannot be displayed on a screen, we need a different technique to determine the focal length of a *diverging* lens. The reason, of course, is that rather than converge the light from a distant object to a (focal) point, a diverging lens will diverge the light so that it appears to be coming *from* a (focal) point. This is shown in the next sketch. A ray from a distant object (simulated by the solid, red laser beam) that enters a lens off-axis is diverged from the axis. If the ray is extrapolated backward (dashed red line at an angle relative to the axis), it intersects the axis (blue line through the center of the lens) at the focal point. The geometry makes it possible to calculate the magnitude of the focal length, $|f|$, as follows. If the amount by which the laser beam is diverged is $y_2$-$y_1$, the distance of the laser beam from the axis is $e$ and the distance from the wall to the lens is $L$, $|f|$ can be calculated from

$$|f| = \frac{Le}{|y_2 - y_1|} \tag{4}$$

In our experiment, we will use a laser beam to simulate light from a distant object. That is possible because *light from a distant object is parallel to the axis,* and it is easy to send a laser beam into a lens parallel to the axis. Proceed as follows.

***Note: Do not let the laser beam shine into your eye i.e. do not look into the laser.***




1. Place the laser on the table about 2 m from the wall and shine the laser on a vertical 2-meter stick at the wall. Record the reading on the meter stick where the laser beam strikes it as $y_1$ in the space provided.

R10: $y_1$ = ________ ± ________ cm

2. *Place the lens in the laser beam so that the position of the middle of the beam at the meter stick does not change*. (The beam will spread out a little. Don't worry about that.) If the position of the beam is unaffected by the lens, the laser beam is striking the middle of the lens. You might turn the lens on its side. In that case, you will need to find just the right height for the lens. Try different "shims" underneath. (Cardboard, paper or the weights from a weight set can be used "shims.")

3. Finally, raise the lens roughly 1 cm by placing an *additional shim* underneath the lens holder. (The jewel box for a Zip disk is a convenient thickness.) **The thickness of the *additional shim* is** $e$. (Yes, $e$ is roughly 1 cm.) Measure the thickness of the *additional shim* and record the value as $e$ in the space provided. The position of the beam on the meter stick at the wall should change by several cm. The new value should be recorded as $y_2$ in the space provided.

R11: $y_2$ = ________ ± ________ cm R12: $e$ = ________ ± ________ cm

4. Finally, measure the distance from the lens to the wall, $L$, and record the value in the space provided.

R13: $L$ = ________ ± ________ cm

5. Calculate the value of $|f|$ from eq. (4). R14: Show your calculation. Because it is a diverging lens, the value of the focal length must be negative. Consequently, record the value of $f_{\text{diverging lens}} = -|f|$ in the space provided.

R15: $f_{\text{diverging lens}}$ = ________ ± ________ cm

**The Lens Equation (Textbook Section 34-2)** Our first goal is to verify eq. (1), the *lens equation*. What we will do is measure $d_i$ (the image distance) for a finite $d_o$ (object distance) and calculate $f$ (the focal length of the lens). The focal length will then be compared with the value determined by "direct" measurement.

1. Arrange the light source/object, the converging lens with the *longest focal length* and the screen on the optics bench as shown in the next sketch.

**Note**: *Be sure that the source/object and bracket are configured exactly as shown in the picture on the first page of this write-up. There are several incorrect orientations that will cause problems. (The light source should be at the same level as the lens and the "notch" at the bottom of the bracket should be toward the lens.)*

**Note**: *Unplug the source/object (light) when it is not in use.*

Place the object close to one end of the optics bench (Consider placing the object at "0" on the yellow graduated scale.) and the screen close to the other end. Be sure that the object and screen are perpendicular to the optics bench. Record the color of the mark on the lens holder and the positions of the object and screen.

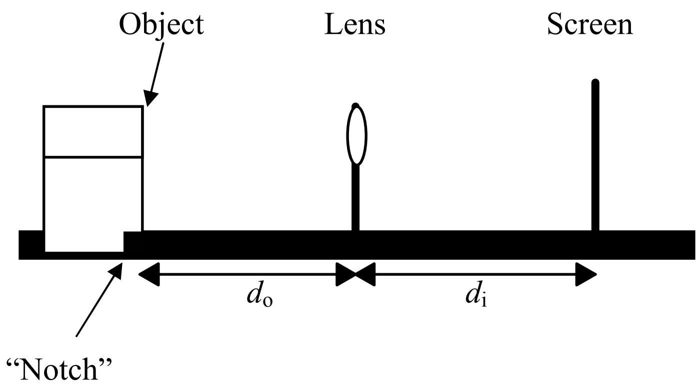
R16: Color of Mark on Lens __________________

R17: Object Position = ________ ± ________ cm

R18: Screen Position = ________ ± ________ cm

3. Starting with the lens near the object, adjust the position of the lens until an image is formed on the screen. Continue to adjust the position of the lens until the image is in focus. Record the position of the lens in the space provided.

R19: Lens Position = ________ ± ________ cm




4. Determine the values of $d_o$ and $d_i$ from the positions and record the values in the space provided.

R20: $d_o$ = ________ ± ________ cm R21: $d_i$ = ________ ± ________ cm

5. Use eq. (1) to calculate the focal length of the lens and record the value in the space provided. Show your calculation.

R22: $f$ (Calculated using $d_o$ and $d_i$) = ________ ± ________ cm

R23: Calculation

R24: How does the value of the focal length compare with the value determined previously for this lens? Discuss.

**Lateral Magnification** Our next goal is to verify eq. (2).

1. Use eq. (2) and the measured values of $d_o$ and $d_i$ to calculate the magnification, $m$, of the lens. Record the value in the space provided.

R25: $m$ (Calculated using $d_o$ and $d_i$) = ________ ± ________

2. Note that the object has a scale marked in mm. Choose a portion of the object to use as the object size and record that as $h_o$ in the space provided. (For example, if you choose the diameter of the inner circle as the size of the object, you will record $h_o$ = 1.0 cm.)

3. Devise a technique for measuring the size of the image. In the space provided, record the size of the image value as $h_i$. (Note: If the image is inverted relative to the object, record the value of $h_i$ as negative.)

R26: $h_o$ = ________ ± ________ cm R27: $h_i$ = ________ ± ________ cm

R28: Describe your technique for measuring the size of the image.

4. Use eq. (2) and the measured values of $h_o$ and $h_i$ to calculate the magnification of the lens. Record the value in the space provided.

R29: $m$ (Calculated using $h_o$ and $h_i$) = ________ ± ________

R30: Compare the two values of $m$. Discuss.

**Other Implications of the Lens Equation** Let us keep the object and the screen at the same positions.

1. Move the lens so that the "new" object distance is approximately equal to the "old" image distance. (The object distance for this experiment is the image distance for the previous experiment.) Adjust the lens so that a new and different size image forms on the screen. Record the values of the object distance and image distance in the space provided.

R31: $d_o$ (new) = ________ ± ________ cm R32: $d_i$ (new) = ________ ± ________ cm

R33: Use eq. (1) to explain why it is expected that a different image is formed if the object distance and image distance are interchanged.

2. Use eq. (2) and the new values of $d_o$ and $d_i$ to calculate the magnification, $m$, of the lens. Record the value in the space provided.

R34: $m$ (Calculated using the new values of $d_o$ and $d_i$) = ________ ± ________

R35: How does the "new" magnification compare with the "old" magnification? Use eq. (2) to discuss your results.

3. Place the lens so that the object distance is significantly less than (about half of) the focal length of the lens. Move the screen in an attempt to locate a real image. (The screen may be removed from the optics bench in an attempt to locate any images that are beyond the end of the optics bench.) R36: Discuss the results of this experiment.

**Combinations of Lenses (Textbook Section 34-3)** As pointed out in the textbook, when light passes through more than one lens, the *image* created by the first lens becomes the *object* for the second lens. The final image is then the image formed by the second lens. These facts provide the opportunity for us to complete our study of a diverging lens. The reason is that while a diverging lens cannot form a real image of a real object, it can form a real image of a "virtual object." The "virtual object," of course, is the image formed by the first lens. What we will do is use a converging lens to form an image then use that image as the object for a diverging lens.

1. Refer to the previous diagram and place the converging lens with the shortest focal length about 20 cm from the light source. We will refer to this lens as lens 1. Adjust the screen so that you have a clear image. Record the positions of the object, screen and lens 1 in the space provided.

R37: Object Position = ________ ± ________ cm

R38: Screen Position = ________ ± ________ cm

R39: Position of Lens 1 = ________ ± ________ cm

2. Calculate the object and image distances, $d_{o1}$ and $d_{i1}$, from the data and record the values in the space provided.

R40: $d_{o1}$ = ________ ± ________ cm R41: $d_{i1}$ = ________ ± ________ cm

3. Use eq. (1) and $d_{o1}$ and $d_{i1}$ to calculate the focal length of lens 1, $f_1$, and record the value in the space provided.

R42: $f_1$ (Calculated using $d_{o1}$ and $d_{i1}$) = ________ ± ________ cm

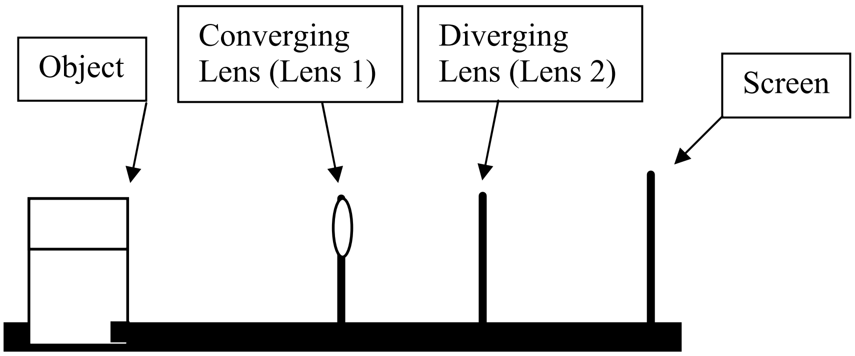
R43: How does the value of $f_1$ compare with that from the "direct" determination (value listed previously)? Discuss.

4. Use eq. (2) and the data to calculate the magnification, caused by the lens 1, $m_1$, and record the value in the space provided.

R44: $m_1$ (Calculated using $d_{o1}$ and $d_{i1}$) = ________ ± ________

5. Place the diverging lens (lens 2) about 10 cm to the right of the converging lens so that the new configuration is similar to the next sketch. In the space provided, record the position of lens 2. (Do ***not*** adjust the position of the screen yet.)

R45: Position of Lens 2 = ________ ± ________ cm




6. Determine the object distance, $d_{o2}$, for lens 2 and record the value in the space provided. (The magnitude of $d_{o2}$ is the distance from lens 2 to the screen.) Explain clearly why $d_{o2}$ must be negative.

R46: $d_{o2}$ = ________ ± ________ cm

7. Adjust the position of the screen to get a new, real image. In the space provided, record the new (final) position of the screen.

R47: Final Position of the Screen = ________ ± ________ cm

8. Determine the image distance, $d_{i2}$, for lens 2. ($d_{i2}$ is the distance from lens 2 to the final position of the screen.) Record the value in the space provided.

R48: $d_{i2}$ = ________ ± ________ cm

9. Use eq. (1) and $d_{o2}$ and $d_{i2}$ to calculate the focal length of lens 2, $f_2$, and record the value in the space provided.

R49: $f_1$ (Calculated using $d_{o2}$ and $d_{i2}$) = ________ ± ________ cm

R50: How does the value determined previously for this (the diverging) lens? Discuss.

10. Use eq. (2) and the data to calculate the magnification, $m_2$, caused by lens 2 and record the value in the space provided.

R51: $m_2$ (Calculated using $d_{o2}$ and $d_{i2}$) = ________ ± ________

Finally, it is shown in Example 34-4 in the textbook that the total magnification, $m_T$, of a combination of lenses is the product of the individual magnifications $m_1$ and $m_2$ i.e.

$$m_T = m_1 m_2 \tag{5}$$

11. Use eq. (5) and the results listed in the table to calculate $m_T$. Record the value as $m_T$ (Calculated using eq. (5)) in the space provided.

R52: $m_T$ (Calculated using $m_1$ and $m_2$) = ________ ± ________

12. Determine the size of the original object (the object at the light source). To avoid confusion, consider using the same portion of the object ($h_o$) that was used earlier in this lab (in the **Lateral Magnification** portion of this lab). Record the value as $h_{oO}$ in the space provided.

R53: $h_{oO}$ = ________ ± ________ cm

R54: $h_{iF}$ = ________ ± ________ cm

13. Measure the size of the final image (the image on the screen) and record the value as $h_{iF}$ in the space provided.

14. Calculate the total magnification using the following equation and record the value in the space provided.

$$m_T = \frac{h_{iF}}{h_{oO}} \tag{6}$$

R55: $m_T$ (Calculated using $h_{oO}$ and $h_{iF}$) = ________ ± ________

R56: Explain why eq. (6) is correct.

R57: Compare the two values of the total magnification. Discuss.

**End of Lab Checkout** Tidy up the work station.